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Search for New Exotic Particles at CDF

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We present recent results of searches for new particles beyond the Standard Model at the Collider Detector at Fermilab (CDF). These include searches for heavy gauge bosons (Z', W'), leptoquarks and stable massive charged particles. For most of this particles we set the currently most stringent limits.

1 Introduction

The Tevatron, a $p\bar{p}$ collider with the currently highest center of mass energy in the world($\sqrt{s}$ =1.8TeV), is in a unique position to explore new phenomena beyond the Standard Model (SM). The broad-band nature of the production process via Drell-Yan or gluons is an advantage for searches. In addition new particles could be produced in top decays and the high b-production cross section allows to set very stringent limits on some rare B-decays.

The CDF experiment is actively searching for new phenomena and sets many of the best limits in direct searches available to date. In this paper we describe some of our ongoing searches for new phenomena. For supersymmetric particle searches at CDF see reference [1].

The datasets were collected during three running periods 88-89, 92-93 (Run 1a), and 94-95 (Run 1b) yielding approximately 5, 20 and 90 pb^{-1} respectively. All limits quoted in this paper are at 95% confidence level.

2 Leptoquarks

Leptoquarks belong to a class of particles carrying both color and lepton quantum numbers which mediate transitions between quarks and leptons. Leptoquarks do not exist within the Standard Model but appear in many SM extensions which predict a symmetry between quarks and leptons at a fundamental level [2,3,4]. At CDF we have performed two fundamentally different searches for leptoquarks which will be described in the following two sections.

[a]representing the CDF collaboration

2.1 *Direct search for pair produced leptoquarks*

Leptoquark masses and coupling strengths are severely constrained by experimental bounds on rare processes, so one has to make the following assumptions about the properties of leptoquarks and their couplings to allow masses which are directly observable in collider experiments:

1. to evade mass bounds from proton decay, lepton and baryon number have to be conserved;
2. to prevent leptoquark-induced FCNC, leptoquarks are generally assumed to link, through an unknown coupling strength, quark and lepton multiplets of the same generation, and
3. to avoid LQ contributions to the helicity suppressed $\pi \rightarrow e\nu$ decay, the couplings have to be chiral.

We have searched for pair production of scalar leptoquarks in the dilepton plus dijet channels ($LQ\overline{LQ} \rightarrow l^+l^-jj$) for all three lepton generations. In the 88/89 run [5], we set a first generation leptoquark (LQ1) mass limit of $M_{LQ1} > 113$ GeV/c^2 for $\beta = 1$ and $M_{LQ1} > 80$ GeV/c^2 for $\beta = 0.5$, where β is the branching ratio for a leptoquark decaying to a charged lepton and quark. Since then, HERA[6] has improved the first generation limits excluding masses up to 275 GeV/c^2 assuming the coupling strength λ to be larger than $\sqrt{4\pi\alpha_{em}}$. At hadron colliders on the other hand the production cross section depends only very weakly on λ. The current D0 limit [7] based on run 1a data is 133 GeV/c^2 for $\beta = 1$.

To search for second generation leptoquarks (LQ2) ($LQ_2\overline{LQ_2} \rightarrow \mu^+\mu^-jj$) we require 2 isolated μ with $P_T > 20$ GeV/c and 2 jets with $E_T > 20$ GeV, events in the Z^0- mass region ($75 < m_{\mu\mu} < 105$ GeV/c^2) are excluded. Analyzing $\approx 70pb^{-1}$ of data we observe 4 events where 4.8 background events, mainly from Drell Yan, are expected. With this we set limits and obtain $M_{LQ2} > 180$ GeV/c^2 for $\beta = 1$ and $M_{LQ2} > 140$ GeV/c^2 for $\beta = 0.5$ which is currently the most stringent limit (D0 [8]: $M_{LQ2} > 111$ GeV/c^2). Figure 1 shows the limit on $\sigma \cdot \beta^2$ as a function of LQ2 mass.

To search for third generation leptoquarks (LQ3) ($LQ_3\overline{LQ_3} \rightarrow \tau^+\tau^-jj$) we require one of the τ's to decay to e or μ with $P_T > 20$ GeV/c, the lepton is required to be isolated and the $\not{E}_T$ was required to point within 50^0 of the lepton direction. The other τ decays hadronically and is identified by requiring that there be 1 or 3 tracks within a 10^0 cone about the jet axis and no other tracks above 1 GeV/c between the 10^0 cone and a 30^0 cone. In addition we require 2 jets with E_T >20 GeV. No b-tag is required. We observe

0 events in $70 pb^{-1}$ of data with an estimated background of $1.2^{+1.0}_{-0.2}$ events (mainly from $Z^0 \to \tau^+\tau^- + jets$). For scalar leptoquarks we set a limit at $M_{LQ3} > 94\ GeV/c^2$. We also considered vector leptoquarks with "anomalous chromomagnetic moments" parameterized by κ. For this type of leptoquark assuming $\beta = 1$, the limits are $M_{LQ3} > 165$ GeV/c^2 and $M_{LQ3} > 222$ GeV/c^2 for κ=0 and $\kappa = 1$ respectively. The results are summarized in Figure 2.

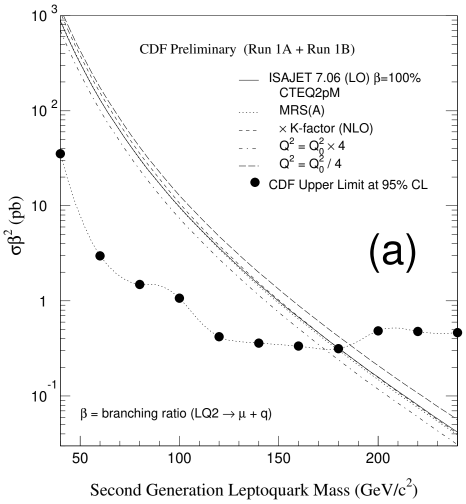

Figure 1: The limit on $\sigma \cdot \beta^2$ is shown as a function of LQ2 mass.

2.2 *Search for the decays $B_s^0 \to e\mu$ and $B_d^0 \to e\mu$*

Within the Pati-Salam model[2], which is based on the SU$(4)_c$ group, the lepton number is regarded as the fourth "color". At some high-energy scale, the group SU$(4)_c$ is spontaneously broken to SU$(3)_c$, liberating the leptons from the influence of the strong interaction and breaking the symmetry between quarks and leptons. This model predicts a heavy spin-one gauge boson with non-chiral couplings called the Pati-Salam boson. The lepton and quark components in this kind of leptoquark are not necessarily from the same generation as pointed out in[9]. This would make decays like $B_s^0 \to e\mu$ and $B_d^0 \to e\mu$ possible. Setting

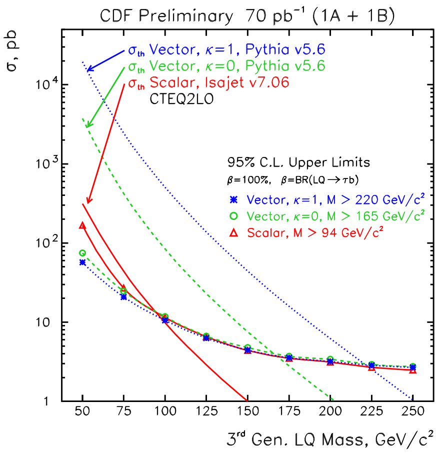

Figure 2: The limit on $\sigma \cdot \beta^2$ is shown as a function of LQ3 mass.

limits on the branching ratio of these rare processes can probe masses in the multi-TeV range, i.e. masses not accessible directly. We have searched for the decays $B_s^0 \to e\mu$ and $B_d^0 \to e\mu$ using $\approx$ 90 pb^{-1} of Run Ib data. We select events with an oppositely charged $e\mu$-pair, the electron with $E_T > 5.0$ GeV and the muon with $P_T >$2.5 Gev/c. In addition we required the proper decay length: $c\tau > 200\mu m$ and that the momentum of the $e\mu$ pair points back to the primary vertex. We find no B_d^0 candidates in a mass window ($\pm 3\sigma$ of our mass resolution) of 5.174-5.384 GeV/c^2 and one B_s^0 candidate in a mass window of 5.270-5.480 GeV/c^2. We set limits at $\text{Br}(B_s^0 \to e\mu) < 2.3 \times 10^{-5}$ and $\text{Br}(B_d^0 \to e\mu) < 4.4 \times 10^{-6}$ after systematic uncertainties have been included. From this we derive a limit on the mass of a certain Pati-Salam leptoquark of 12.1 TeV/c^2 for the B_s and 18.3 TeV/c^2 for the B_d.

3 New Gauge Bosons Z' and W'

Heavy neutral gauge bosons in addition to the Z^0, generically denoted as Z', occur in any extension of the Standard Model which contains an extra U(1) after symmetry breaking. The couplings of the Z' depend on the specific model. Examples are Z_{LR} which appears in Left-right symmetric models or one model based on E_6 as the grand unified gauge group [10] contains a Z_ψ from the symmetry breaking $E_6 \to SO(10) \times U(1)_\psi$ and a Z_χ from the symmetry breaking $SO(10) \rightarrow SU(5) \times U(1)_\chi$ [b]. A Z_η defined as $Z_\eta = \sqrt{3/8}Z_\chi + \sqrt{5/8}Z_\psi$ appears in a Superstring motivated E_6 model. A convenient way [c] to gauge the limits is the introduction of a Z'_{SM} which is assumed to have the same couplings as the Z^0.

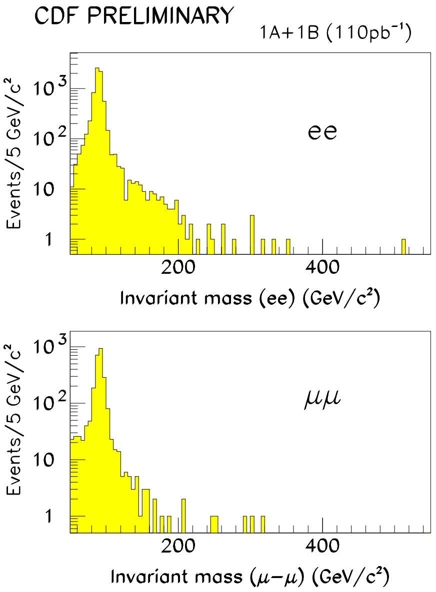

Figure 3: The dielectron and dimuon invariant mass distributions for the Z' search data sample.

We have searched for Z' in both dimuon and dielectron decay modes with 110 pb^{-1} of Run Ia and Ib data. Figures 3 and 4 show the invariant mass distributions of dimuons and dielectrons in the Z' search data sample and the comparison of data with background predictions. The 95% C.L. limit on the cross section times branching ratio to dileptons that we obtain is shown as a function of mass in Figure 5. We can use this experimental result to set limits on the Z'-mass for different models. Assuming Standard Model couplings we obtain $M_{Z'} > 690$ GeV/c^2 (see Figure 5). We also compared the experimental limit with specific models. We set the lower mass limits for Z_ψ, Z_η, Z_χ, Z_I, Z_{LR} and Z_{ALRM} to be 580, 610, 585, 555, 620, and 590 GeV/c^2, respectively assuming the Z' decays only into known SM fermions.

[b] The SU(5) symmetry then breaks to recover the Standard Model: $SU(5) \rightarrow SU(3)_C \times SU(2)_L \times U(1)_Y$.

[c] not necessarily motivated theoretically.

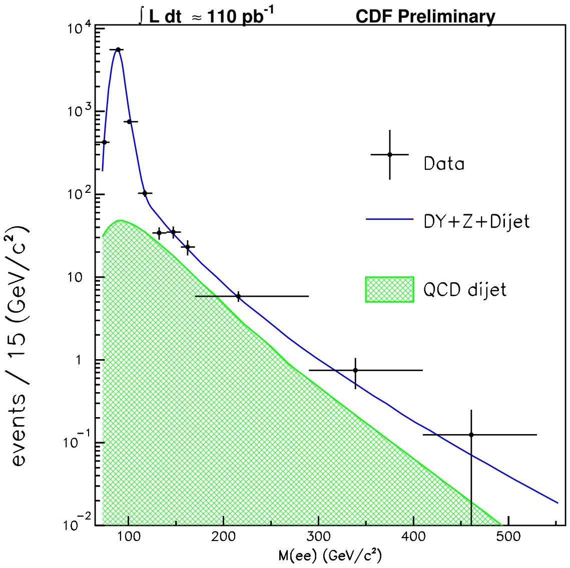

Figure 4: The dielectron invariant mass distributions compared to background predictions.

Heavy W bosons, W', occur in extended gauge models with an extra $SU(2)$, for example, the left-right symmetric model [11] of electroweak interactions $SU(2)_R \times SU(2)_L \times U(1)_Y$. CDF has searched for $W' \to l\nu$ in the electron and muon channels [12,13]. The analysis of Run Ia electron data yielded a limit of $M_{W'} > 652$ GeV/c^2, assuming Standard Model couplings and that the decay $W' \to WZ$ is not allowed. The search for $W' \to e\nu$ and $\mu\nu$ using Run Ib data is in progress.

We have also performed a search for W' decaying to WZ [14] where the Z is identified by requiring two jets with invariant mass close to the Z^0-mass. In extended gauge models W and W' are not mass eigenstates and so mixing must occur. We have excluded a region in the mass vs. mixing angle ($\xi \equiv c\left(\frac{M_W}{M_{W'}}\right)^2$) space. This region is shown in Figure 6. Searches for $W' \to tb$ and $W' \to WH$ are in progress.

We have also searched for $Z' \to q\bar{q}$ and $W' \to q\bar{q}$ in the dijet channel using the entire run I dataset but the cross sections [d] are too small compared to the QCD dijet background to be excluded by our data.

[d] assuming standard model couplings

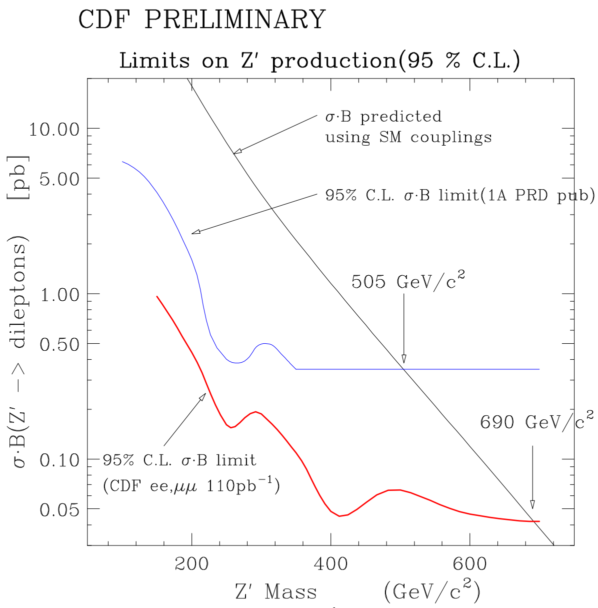

Figure 5: Limits on Z' production.

4 Massive Stable Particles

Massive stable particles are possible features of several theories[15] for physics beyond the standard model including supersymmetry, mirror fermions, and higher color multiplets. If such particles were charged, they could be detected directly in CDF's tracking chambers. We have searched for heavy stable charged particles based upon their expected high transverse momenta, relatively low velocities, and muon-like penetration of matter. Low velocity particles are distinguished by their large ionization deposition, dE/dx. CDF measures dE/dx with both its central tracking chamber (a gaseous wire chamber) and its silicon vertex detector (a solid state detector). Combining the two measurements provides strong rejection of minimum ionizing particles (MIPS) while maintaining efficiency for tagging particles with low velocity, $\beta\gamma < 0.65$.

We have searched in 48 pb^{-1} of Run Ib data. Because of their properties this particles should fire our muon triggers and be part of our inclusive muon sample. Requiring the transverse momentum $p_T > 30$ GeV/c, the dE/dx to be at least 1.8 times bigger than expected for a MIP in the central tracker and at least 2.5 times bigger in the silicon tracker, we observe no candidates. This non-observation can be used to set limits on a variety of theories. We have

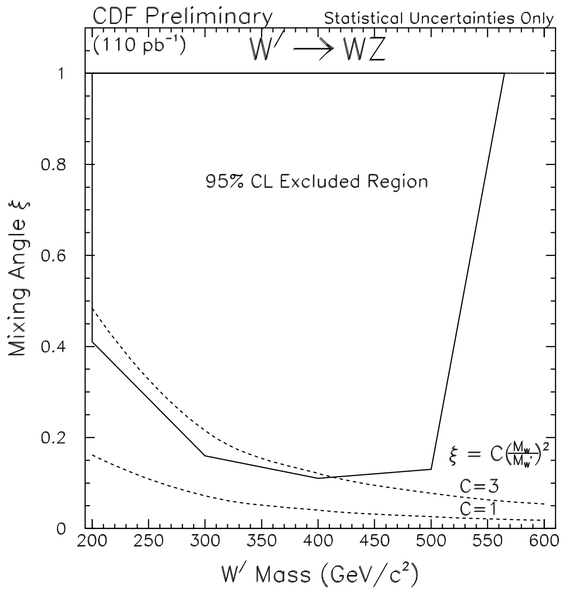

Figure 6: Limits are shown for $W' \rightarrow WZ$.

thus far only addressed the simplest case; a stable color triplet quark. For that case, we have obtained a preliminary limit of $190GeV/c^2$, as shown in Figure 7. The remaining data will be analyzed soon, and the limit will be extended to other models.

5 Summary and future prospects

Performing direct and indirect searches for a variety of exotic particles has found no evidence for such particles. We set many of the currently best limits on physics beyond the Standard Model. Several of the analysis presented in this paper used only a subset of the current dataset and will clearly benefit from using the full 110 pb^{-1} of run 1.

We are currently upgrading the CDF detector. The upgrades include new integrated tracking with better pattern recognition and improved coverage, improved calorimeter, muon, and b-tagging coverage, and the ability to trigger on b jets. With the upgraded detector and 2 fb^{-1} of data, our reach for new physics will be substantially increased.

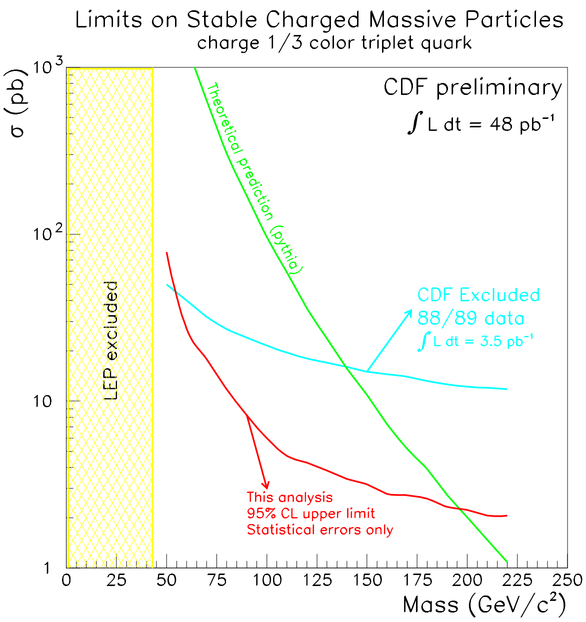

Figure 7: Limits on stable charge 1/3 color triplet quarks.

Acknowledgements

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